Insuring Consistent Synthetic Environmental Representation Across an Engineering Federation- A First User Case

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ABSTRACT: *This paper describes a collaborative effort between the Maritime Virtual Environment Data Specification (MARVEDS) initiative and the Integrated Ship Defense (ISD) Modeling and Simulation (M&S) Pilot Program. The effort's objective is to insure a consistent synthetic natural environment as part of a comprehensive ISD simulation capability. The ISD Federation tests the ISD systems ability to fulfill the ship defense mission, i.e., detect, control and engage.*

The paper will discuss the data and effects modeling needed to create a consistent environment representation for the ISD M&S Pilot Program, the process for identifying "just enough" environment, and the contribution of this program-specific collaboration to the larger MARVEDS specification evolution. Many M&S infrastructure efforts follow a top-down implementation approach. However, many customers need capability in the near term, to address an analysis or project-specific need. This often leads to the use of legacy systems that have embedded environments that may not be consistent across all members of the Federation. Further, all simulation must be cost-effective, including the environment representation portion.

In achieving a consistent and cost-effective environment representation the paper discusses the nature and composition of the engineering team; the development of repeatable, extensible process for performing work cost-effectively; the use of a new tool, the environment concept model; and the relationship between a project-specific environment concept model and a more general, evolving environment specification.

Results of the collaboration show that it is possible to achieve a consistent environment representation using legacy code embedded within Federates. Further, there is a repeatable process, which fosters consistency, independent of the Federation implementation configuration. Finally, the products of incremental environment-building efforts can be integrated into an overall environment specification initiative.

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1. Introduction

Based on the common need to create the basis for a unified environment representation, several major acquisition programs have cooperated to jointly develop a plan of action. The Maritime Virtual Environment Data Specification (MARVEDS) Initiative's objective is to develop the data specifications to enable a virtual prototype (VP) to interact with a maritime virtual environment. The goal is a verified, validated synthetic environment usable by multiple VPs throughout their lifecycle. MARVEDS is leveraging work in progress by the Defense Modeling and Simulation Office (DMSO) Environmental Executive Agents and providing any and all environment representations developed by MARVEDS participants to the established joint databases.

The MARVEDS Working Group is the coordinating body for MARVEDS activities. As of 10 August 1998 the Working Group was composed of representatives from the Program Executive Offices (PEO) for Theater Air Defense/Surface Combatants (TAD/SC) and Undersea Warfare; from the Joint Strike Fighter, 21st Century Surface Combatant, Aircraft Carrier, and Battle Force Tactical Training acquisition program offices; from the Oceanographer of the Navy, and Navy Test and Evaluation and Modeling and Simulation policy offices.

The ISD M&S Pilot Program is an Advanced Distributed Simulation Technology development program being conducted by the PEO TAD/SC. "The goal of the ISD M&S Pilot Program is to develop and demonstrate a comprehensive modeling and simulation capability in support of the design and evaluation of components and systems directed towards phases of the ship defense mission, i.e., detect, control and engage. To this end, a comprehensive program plan was prepared in FY96 that details an approach to federating existing simulations in compliance with the High Level Architecture (HLA) to support PEO(TAD/SC) system acquisition decisions. [1] "

This paper describes a joint project conducted by MARVEDS staff and the ISD M&S Pilot Program to develop a consistent, cost-effective, environment representation for the ISD Pilot Phase I Demonstration.

2. MARVEDS, ISD Technical Approaches

2.1 MARVEDS

When real system or object behaviors, at any level of detail, are affected by their environment, then realistic model representations must include both data and algorithms which account for environment effects and environment impacts; in other words, "environment-aware models".

Figure 1, the environment reference model, shows different forms of environment representation, and how environment representation affects predicted object behaviors or warfighting performance. Environment is represented by combinations of data, environmental effects (data or algorithms) and environmental impacts (data or algorithms). Synthetic environment effects, like propagation loss, and object model behaviors, like explosions creating smoke or craters, alter environmental state.

Environment Simulation   **Object, Behavior Simulation**
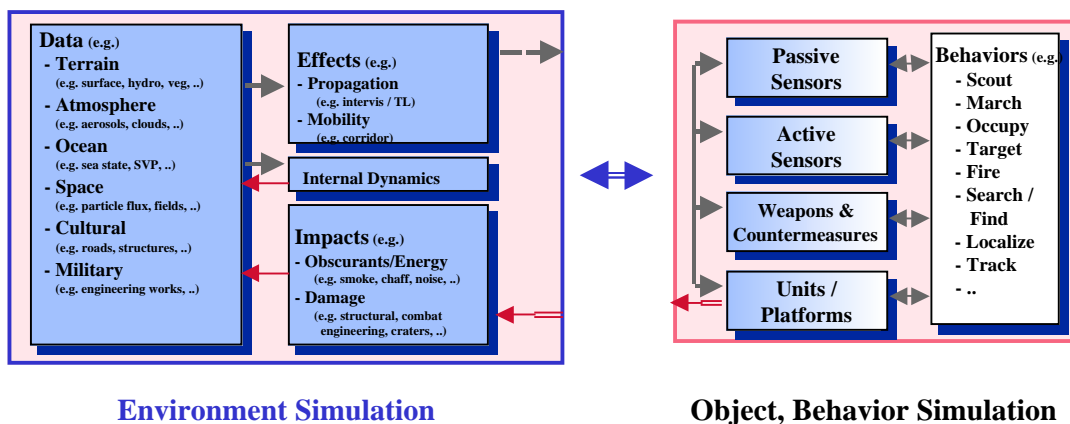
Figure 1 Environment Reference Model

Because environment representation, object models and object behaviors are so clearly linked, valid virtual prototype behaviors require consistent environment representations. Colloquially expressed, a consistent environment representation means that "everyone plays on the same day". More rigorously, consistent synthetic natural environments provide representations that are valid to a chosen resolution, and are spatially, temporally and spectrally continuous.

Because of the scope of the needed synthetic environment representation, MARVEDS adopted a technical strategy that combines top-down planning with bottom-up, incremental information engineering. The MARVEDS Working Group works together to ensure that MARVEDS remains focused, leverages related work and incorporates MARVEDS information engineering efforts into draft specifications/standards. MARVEDS technical teams, working collaboratively with key programs, perform individual information engineering projects whose aim is to provide those key programs with consistent synthetic natural environments. The information engineering approach treats each project as a use case, describing the needed

environment representation, identifying leveragable data, models and tools, and providing guidance to program personnel. The output of each project is added to the body of commonly available environment representation documented in ongoing specification/ standards development efforts. In this way MARVEDS works to create the infrastructure that enables consistent environment representations.

2.2 ISD M&S Pilot Program

The ISD M&S Pilot Program will focus on new technologies critical to developing an infrastructure that supports the consistent use of simulation in all phases of the acquisition life cycle. These technologies include the DMSO Runtime Infrastructure, high-speed wide-area networks, high-fidelity representations of platforms and threats, ship defense combat system simulations, coherent environment representations, and interaction between engineering and joint operational Federations. Figure 2 shows the elements that will be represented in the Pilot Program Phase I Federation.
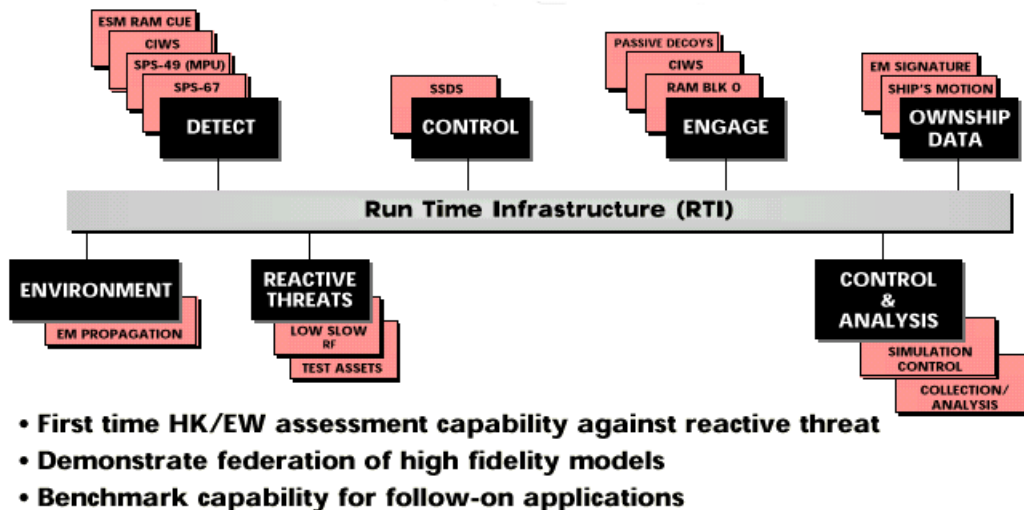

Figure 2. ISD Federation Phase I Implementation

The Pilot Program will be completed in three phases. Phase I concentrates on test and evaluation, Phase II on development and system procurement, and Phase III on research and development. The Phase I objectives are to: create a detailed engineering-level representation of the LSD-48 ship self-defense system; assess a test scenario contained in the LSD-48 Test and Evaluation Master Plan (TEMP); compare simulation results against actual results; document differences to adjust the Federation and; evaluate the simulation's ability to supplement or supplant live T&E and extend test results to additional tactical scenarios. In developing the Phase I Federation configuration, the ISD M&S Pilot Program followed the Federation development and execution process, and used version 1.03 of the DMSO Runtime Infrastructure.

In the fall of 1997, the ISD M&S Pilot Program technical director requested that a MARVEDS technical team develop an environment representation to fully support the ISD Pilot Phase I Demonstration and act as the foundation for the more extensive environment representation required by the Phase II effort. Further, the MARVEDS team was requested to develop and document an environment construction process that would result in "just enough" environment representation for the ISD Pilot Phase II and Phase III efforts.

3. ISD Engineering Federation Use Case

[Authors' Note: What follows is a description of teamwork. For convenience' sake the narrative employs the first person plural, but the pronoun denotes all MARVEDS and ISD Pilot Program participants, not just the authors.]

3.1 Environment Team

Constructing consistent environment representations can be a repeatable process, but the key to consistent environments lies in people. In developing the ISD Pilot Program Phase I environment representation we found that we used a multidisciplinary team composed of the following roles:

      a. Federation system engineers, to develop and execute the Federation (the user perspective)
      b. environment system engineers, to give environment implementation guidance to the Federation system engineer
      c. Federate developers, to develop and integrate individual Federates

      d. environment domain experts, to review the content and context of data and effects/impacts algorithms
      e. an environment specification liaison, to incorporate use case products into the overall MARVEDS specification/standard.

We found that consistent environments depend on the technical interchange between user-community Federate developers and provider-community domain experts, moderated by systems engineers. However, it's not necessary that each role be filled by a unique team member (multi-talented team members may fill several roles); the level of participation should correspond to the workload.

3.2 The ISD Mission Space

To assist the ISD Federation system in insuring a consistent representation of the environment across the entire ISD mission space it was important that the MARVEDS team develop a clear understanding of the ISD mission space. The mission space is bounded by the detection range of the AN/SPS-49 Radar, launch range of the Rolling Airframe Missile (RAM) and detection range of the Close-In Weapon System (CIWS) and the environment within this space. Within that mission space a typical scenario, from the Test and Evaluation Master Plan, might consist of the LSD-48 steaming at 20 knots approximately 15 miles off shore when one or more incoming contacts are detected by the AN/SPS-49.

Operating cooperatively, the AN/SPS-49 search radar provides the initial contact detection and localization. All the track data from the radar is automatically provided to the Ship Self Defense System (SSDS) which evaluates all tracks, develops quality estimates and passes track information on to direct the RAM and CIWS. As the range closes, SSDS determines the "best" target position, and provides the order for engagement to the RAM launcher. Once the RAM is launched, its multi-sensor seeker searches to detect the target signature. RAM then attempts to intercept and destroy the target. CIWS, as the system of last resort, is also tracking the target and is ready to fire if the RAM missile were to miss.

The ISD mission space executes quickly, in a few minutes at most. Thus there is no need to attempt to represent dynamic weather patterns. The frequency bands of interest are the UHF, X, and KU bands in RF, and the medium wave IR band. The ship sensors and weapons and the threat missile(s) all operate near the

sea surface where propagation effects are highly dependent on height of the sensor, altitude of the sea skimming target, grazing angle, ducting, subrefraction, and horizontal fades, as well as shore and sea surface background clutter. This context information is important to establishing "just enough" environment representation. We found it useful to capture this information in a context diagram, showing the spatial, temporal and spectral elements of the scenario(s) of interest.

3.3 Federate Environment Content

The ISD Federation combines legacy models, including environmental representations of varying fidelity, which are being adapted and a newly developed model to represent the SPS-49 radar. For the environment to be consistent across the entire Federation the data and the calculated effects must be spatially, temporally and spectrally coherent. The environment may use the same set of environmental data for the particular time and place, yet the effects modeled for that environment may not be consistent due to the resolution, level of detail, commonly called fidelity, of the models within the Federation.

As a first step in determining the environmental content and interaction between each Federate the environment system engineers consulted the draft ISD Federation Object Model (FOM), and any Simulation Object Model (SOM) documentation. Because the Federation uses embedded environment representations, the FOM indicated that there was no environment-related runtime interaction between the Federates. (We believe that this situation often occurs when legacy models are used.) Next, the environment system engineers met with each of the Federate developers to discuss and understand their individual models, environment content, how the environmental data was used, what outputs were developed and to whom those outputs were routed. The ISD Phase I context set the bounds for the discussions. In almost every case it was necessary to consult the model documentation, and in one case the environment system engineers and environment domain experts augmented their understanding by reviewing source code.

From our discussions we determined that the AN/SPS-49 radar Federate accounts for the environmental effects of multipath, clutter, jamming, Doppler, angle of arrival, and propagation loss. The CIWS Federate environmental model includes the effects of multipath and sea clutter during the search and track process. The multipath model uses sea state as an input, but sea clutter is internally generated by the simulation using

no environmental inputs. The CIWS simulation does not include the effects of low altitude ducting and its impact on the detection and tracking process. The SSDS Federate currently has no environmental parameters. The RAM Federate applies no externally modifiable environmental factors for the RF signal it intercepts and models only an absorption factor for the irradiance detected. Attenuation of the RF is not included. Multipath effects, wind, and atmospheric content are all factors that could effect the RAM performance but are left to a future upgrade. The ISD pilot phase II will use a more sophisticated RAM missile model as the simulation transitions from the RAM Block 0 seeker to the RAM Block 1 seeker with an accompanying enhanced environmental model.

3.4 Federate Environment Data Needs

Since the ISD Federation is configured using mostly legacy simulations the environmental engineer was able to gather documentation from all of the Federate engineers. It was straightforward for the environment domain experts to review the documentation and develop a matrix showing what environment parameters were needed by each Federate. The AN/SPS-49 is the most input data dependent, while the RAM requires the least. The CIWS Federate engineer did provide a list of inputs required by the CIWS embedded environmental model. The data inputs are minimal consisting of temperature, rain rate, visibility (not used in the models) and sea state, while the RAM requires a predetermined atmospheric plot based on the U.S. Standard atmosphere and an irradiance versus range set of curves for the targets in the scenario(s).

It was clear that all Federates can be provided data that is consistent across the entire Federation. It was also clear that environmental data was not being shared between Federates. Each Federate required its own set of environment parameters for use within its model. Thus, consistent environment representation across the Federation could be achieved by constructing a common database for all Federates to draw upon. The database would be available at run time for all Federates to draw upon as needed.

As we uncovered the various data types needed to support the objects in each Federate there appeared to be a direct correlation between data needs and Federate fidelity. Although the environmental data used for each system is correct for the same day, time of day, location, etc., how the data is used within the Federates environmental model is significantly different, ranging from very low fidelity for the RAM block (0) to very high for the AN/SPS-49 radar.

3.5 Environment Effects Models and Fidelity

The AN/SPS-49 search radar Federate is incorporating an updated version of the Photon Research Associates physics based RADar SIMulation (RADSIM) model. RADSIM is a comprehensive high fidelity radar sensor simulation that couples background scenes using Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD) and associated environmental factors (propagation loss, wind direction, multipath, grazing angle, ducting, diffraction, precipitation, etc) with the sensor model. The environmental model coupled with RADSIM is the Variable Terrain Radiowave Parabolic Equation model. VTRPE is a range dependent, tropospheric microwave propagation model that uses the split step Fourier electromagnetic parabolic wave equation algorithm [2]. The applicable frequency range is 100mhz to 100ghz. VTRPE, in addition, has a well-defined set of input data needs. The approach taken by the AN/SPS-49 Federate uses the most comprehensive environmental model of all the ISD Federates.

The CIWS model was developed by Hughes (Raytheon) and has been used for many years. It is in the process of being updated. From the documentation we have available the environmental modeling within the overall CIWS model is quite limited. Excluding the environmental parameters used to determine the motion of the platform the only environmental parameter used by the CIWS is sea state. The radar power loss equation is only dependent on range. There is the capability to add a sea state dependent multipath term and a clutter effect based on a standard set of range dependent distributions independent of operating location. The CIWS Federate does not include any capability to represent the atmosphere, fog, rain, ducts or any other phenomenon that could impact the quality and hence fidelity of the CIWS radar return. No data or reports were available to us that discussed whether the impact of these environmental factors had been investigated and found to be of marginal benefit or otherwise.

The RAM block (0) simulation has embedded within the sensor model a very straightforward irradiance equation that assumes a point source target and atmospheric attenuation. The atmospheric properties are derived from the U.S. standard atmosphere model. For the ISD Phase I Demonstration this will be updated to be representative of the area chosen for the ISD tests. The RF seeker power loss model assumes no atmospheric attenuation or any other losses. There currently are no models in the RAM Federate to

account for clouds, humidity, wind gust, sea state, temperature, rain etc.

Realizing that the ISD Phase I effort would be constrained by legacy models, we expected that the synthetic environment would be represented at various levels of fidelity by the Federates. This proved true, and we needed to answer two key questions. First, with a consistent data set representing the environment, what is the impact of varying fidelity effects models on the Federation? Second, is the environmental awareness and fidelity within each Federate and the Federation sufficient to result in an operationally consistent environment?

3.6 How Much Environment is Enough?

Everyone on the ISD M&S Pilot Program team was keenly aware of the need for cost-effectiveness, building "just enough" functionality into the Federation to satisfy Phase I objectives. In this instance we faced an advantage in determining sufficient (environment representation) functionality. Because the ISD Federates are models of existing systems, existing system operational experience influenced the functionality and behaviors to be modeled, and the resulting models reflected judgements about the actual systems' operationally significant behaviors. In the same vein, top level assumptions about the systems' response to environmental factors influenced the level of "environmental awareness" in each model. For instance, the AN/SPS-49 model includes the actual system's flexible multimode capability to enhance background clutter rejection, and the embedded clutter model requires high fidelity representations of terrain and cultural features in littoral scenarios. On the other hand, the RAM Block 0 seeker model (which also faithfully reflects the real seeker's response to environmental factors) does not require a background clutter representation, because the actual seeker performance is extremely insensitive to background clutter. In both instances the models are sufficiently "environmentally aware" to change their operationally significant behavior in response to environment state changes.

The legacy models had been designed to represent the live systems operating independently. But the ISD Phase I Federation models these systems operating cooperatively as part of a ship self defense system. The environment system engineers, working with the Federate developers reviewed Federate interactions as described by the FOM interaction diagram. In reviewing the individual Federate documentation (and in one instance, model source code), we determined that there were no instances where the models of

systems contained internal logic that assumed environment-induced behaviors by other systems.

Finally, we reviewed the Federation environment representation (both data and effects models functionality) in the context of comparisons between live range conditions and simulated conditions. We determined that the insitu environment parameter measurements in the LSD-48 OT&E documentation were consistent with the environment parameters used by the Federation. However, other research [3] had suggested that there might be substantial undocumented variance in the propagation loss experienced during the OT&E due to possible ducting with horizontal fade. We determined that if such atmospheric conditions existed during the OT&E, the environmental effects could be reproduced by the VTRPE high fidelity propagation effects model.

As a result of these three investigations, we were able to determine that the Federates, individually and as a Federation, contained sufficiently detailed environment representations (fidelity) to meet the objectives of the Phase I Demonstration.

4. Capturing the Process: The Environment Concept Model

Early in the collaboration effort, we realized that the team's environment work needed to be documented. We understood that the document would live and grow as the ISD Federation expanded for Pilot Program Phases II and III. Further, the environment data and models used in Pilot Federation would be reused, by other programs using the ISD engineering Federation, and by other Federations requiring low sea surface and low altitude atmospheric environment representations covering RF and IR bands in littoral regions. Finally, the MARVEDS Working Group expected that the ISD environment representation would be captured as part of the continuing MARVEDS specification/standards development effort.

In reviewing the guidance for the preparation of Conceptual Models of the Mission Space (CMMS), FOMs and SOMs we realized that these documents were not intended to capture the issues we addressed in developing the consistent environment representation for the ISD Phase I Federation. As the environment system engineers discussed the options, it became clear that some form of documentation was required. To be most useful, the document should be detailed, and

Federation-specific, like a FOM[1]. At the same time, we felt that reuse would increase if the document were not tied to a single implementation approach (central environment server, distributed server, static data structures, etc.). It would also be very useful if document content could be easily transferred to the MARVEDS specification/standard. We called our solution the environment concept model.
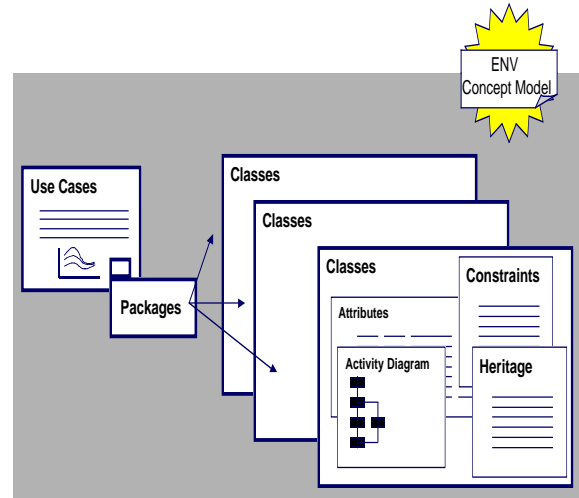

Figure 3. Environment Concept Model

The environment concept model defines the purpose, structure and scope of environment representation for a Federation. It addresses data, algorithms and models. Up front, a use case description captures the context of the Federation application. Packages composed of classes describe the attributes and heritage information for data and algorithms. Model class descriptions include summaries of processing flow as activity diagrams. Both algorithm and model class descriptions include descriptions of constraints; limitations of domain and range of fidelity. Where classes are logically related, the environment concept model captures this relationship in interaction diagrams. By intent, an environment concept model can be created using UML constructs, to leverage emerging capabilities in round trip software engineering. (Our investigation reveals that the data description portion of an environment concept model created in UML can be translated into IDEF1X, so that Federation data structures can be directly compared with DOD data sources.)

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[1] The MARVEDS program is now investigating whether the concept of a reference FOM which represents a category of Federation implementations might also be applicable to the Environment Concept Model

Because the environment concept model does attempt to associate environment classes with other components of the Federation via interaction diagrams, and does not include runtime state diagrams or collaboration diagrams, the representation is not restricted to a unique implementation. Indeed, in developing the environment concept model the environment system engineers explicitly attempted to preserve implementation as the domain of Federation system engineers, who must weigh the cost and time to implement environment representations against the expected value added to the Federation.

The ISD Federation environment representation description is the prototype environment concept model. It successfully captures the results of the environment information engineering process. The initial environment concept model appears to be both extensible (to the ISD Phase II Federation) and portable (for collaboration with the Joint Strike Fighter Programs Virtual Strike Warfare Environment); planned MARVEDS FY99 collaboration projects will test our assertions.

The MARVEDS specification captures the extensible, reusable information generated through the Federation implementation process. The environment specification is intended to capture both the structure of implemented environment representations, and information about implementation resources. To the maximum extent possible, the specification content is drawn directly from activities performed while developing the environment concept model. The specification should be incorporated into a standards process.

5. Summary

In conducting our first use case with the ISD Federation it was important for us to examine the scenario context and system operations to make informed comments about the applicability of particular data sets and environment effects algorithms. The Federation objective and the context had to be explicitly identified and described for matching available data and effects models. This lead to the concept of "just enough."

Implementing a "just enough" consistent environment required an interdisciplinary, team effort. The environment system engineers developed an in-depth understanding of the systems to be modeled by working with the Federation developers and reviewing the environmental and fidelity needs of the Federates and Federation. As the process proceeded the

Federation developers were offered insights by environment domain experts in terms of reference familiar to them.

We recorded the important information acquired at every step in the process. We then documented the actionable environment-building information in a new form, the environment concept model. The environment concept model supports the spirit and purpose of the DMSO Federation execution process.

As we prepared for the ISD M&S Pilot Program Phase II effort, the team realized that there would be enhanced Federation objectives, scenarios, and systems. We also determined that a consistent environment could be assured by using the same investigative and analytical process used during Phase I and that the same documentation formats could record our findings. The environment concept model appears to be robust and need not be rebuilt; the structure and format are able to accommodate the additional content. The environment concept model became the principal source document for our MARVEDS specification/ standards effort.

6. References

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